Supply Chain Infrastructure Restoration Calculator Software Tool: Developer Guide and User Manual

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Conversion Factors

International System of Units to U.S. customary units.

Multiply	By	To obtain
	Area	
square meter (m^2)	10.763	square meter (sq. ft..)
	Length	
kilometer (km)	0.621	mile (mi)
	Power	
watts (W)	0.001	kilowatts (kW)
	Volume	
liter (L)	0.264	gallon (gal)

Abbreviations

GIS	Geographic Information System
SCICI	Supply Chain Interdependent Critical Infrastructure
SCIRC	Supply Chain Infrastructure Restoration Calculator
XML	Extensible Markup Language

Abstract

This report describes a software tool that calculates costs associated with the reconstruction of supply chain interdependent critical infrastructure in the advent of a catastrophic failure by either outside forces (extreme events) or internal forces (fatigue). This tool fills a gap between search and recover strategies of the Federal Emergency Management Agency (FEMA) and construction techniques under full recovery. In addition to overall construction costs, the tool calculates reconstruction needs in terms of personnel and their required support. From these estimates, total costs (or the cost of each element to be restored) can be calculated. Estimates are based upon historic reconstruction data, although decision-managers do have the choice of entering their own input data to tailor the results to a local area.

Introduction

Supply Chain Interdependent Critical Infrastructure (SCICI) has been defined as those elements of the national infrastructure which are so vital that their incapacity or destruction would have a debilitating impact on the defense or economic security of the United States (Department of Homeland Security, 1996). Modeling SCICI restoration is a challenging problem (Ramachandran et al. 2015; Ramachandran et al. 2016). The innate interdependencies between various critical infrastructures add to the complexity of the system. Extreme events such as earthquakes, hurricanes, and the like, can disrupt various critical infrastructures leading to considerable economic losses. Based on the severity of the extreme event, one or multiple infrastructures can be rendered partially or completely inoperable.

This report presents a developer's guide and a user tutorial for a supply chain infrastructure restoration calculator (SCIRC) tool that estimates the amount of resources required to restore

infrastructure networks. This tool was developed as part of a joint effort between the Center of Excellence in Geospatial Information Sciences (CEGIS) at the U.S. Geological Survey and the Engineering Management and Systems Engineering Department at the Missouri University of Science and Technology. For this report, resources include: potable water, gray water, food, sanitation facilities, housing, transportation and other basic requirements of restoration crews along with the supplies (such as power, fuel, materials, and costs) required for restoring these infrastructures. It is important to estimate the amount of resources required to restore disrupted critical infrastructures to devise efficient disaster restoration and management strategies. This tool can be used by city planners and policy makers to calculate the amount of resources required for restoring one or multiple infrastructures to its normal operating state and for budgeting and prioritizing post-disaster restoration operations.

The SCIRC tool is written as open-source software in the Python programming language and uses a bottom-up cost estimation technique to collect data associated with each infrastructure facility. These data include the amount of resources required to build a unit of each infrastructure element. For example, the amount of power, fuel, potable water, storage area, man-hours, food, materials, gray water, solid waste and black water required to build one square foot of a high school. These data are collected for each of the infrastructure elements represented in the SCIRC tool. The estimation of cost, material, and number of restoration crew necessary for disaster recovery is a unique feature of the SCIRC tool. Once this information is available, policy makers will be able to make more efficient decisions regarding the allocation of the resources for disaster restoration.

Software

The SCIRC tool is written in the Python 2.7 programming language. The SCIRC algorithm (fig. 1) is designed to solve a system of equations to simultaneously determine resource requirements using established methods (Nottage and Corns, 2011). The SCIRC tool application queries the user to input the number of units of an infrastructure element that needs to be restored and then returns the amount of resources required for restoration, or in the advent of a large-scale disaster, the user can also calculate the amount of resources required to restore multiple infrastructure elements.

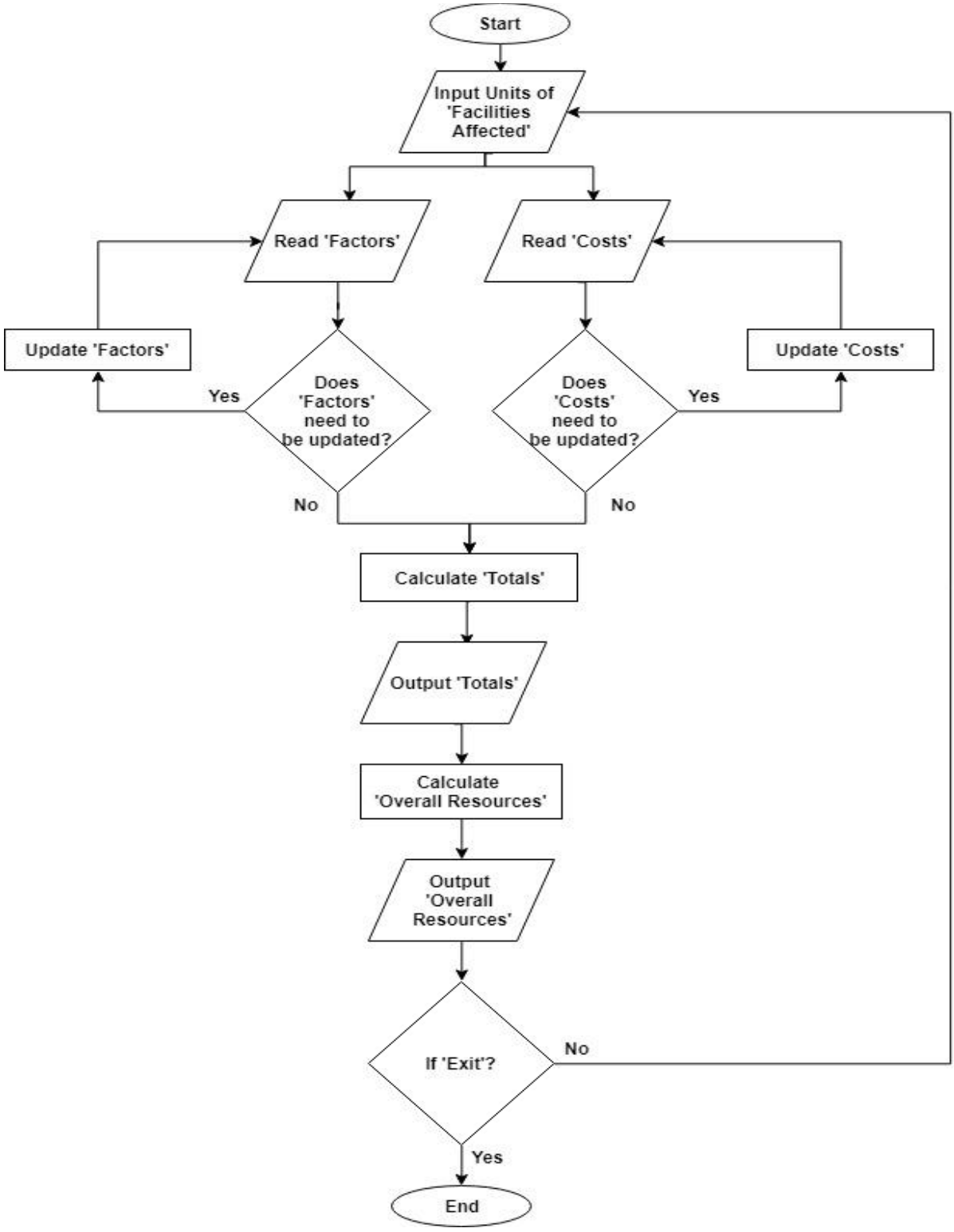

Figure 1: Algorithm for the SCIRC tool.

The SCIRC tool includes five tabs:

1. Facilities Affected – This tab includes a list of infrastructure elements from which the user can choose one or many to restore. The thirty infrastructure elements that are included in the software along with their units are listed in table 1.

2. Factors – This tab delineates the different resources required to restore each unit of a selected infrastructure element. The user selects an element from the drop-down menu available in the factors tab to determine the amount of resources required to build a unit of that element. While standard values for the resources required to restore one unit of an element are default values in the software, the tool does provides the user with an option to change these values in the factors tab based on their expertise or locale. Different types of resources, along with their units, are listed in table 2.

3. Totals – This tab lists the amount of each resource required to restore the infrastructure elements specified by the user. The user selects an element from the drop-down menu in the totals tab to calculate the amount of resources needed to restore the specified number of elements. Along with the resources included in the Factors tab, the Totals tab also includes a total cost estimate, specifically the summation of all costs of the required restoration resources.

4. Costs – This tab lists the unit costs of each resource. The values in the cost tab are pre-fed in the software. The software provides the user with an option to update the costs in the application. It is important to note that the costs of resources provided in the costs tab refers to the cost of one unit of each resource, whereas the cost provided in the totals tab refers to the total cost of restoring a specified number of units of an infrastructure element as specified by the user.

5. Overall Resources – This tab lists the resources required to restore all the infrastructure elements specified by the user. The tab sums the individual resources required to restore each of the elements and reports the totals. In other words, if the user inputs in the Facilities Affected tab a request to restore one infrastructure element, the Overall Resources tab will return the resources required to restore that element, whereas if the user requests restoration of ten occurrences of a given infrastructure element in the Facilities Affected tab, the Overall Resources tab will provide the amount of resources required to restore these ten elements.

FACILITIES	DESCRIPTION	UNITS
Electrical Distribution	Electrical power lines to deliver electricity	miles
Coal Power Plant	Coal-based power plants for electrical generation	kW
Nuclear Power Plant	Nuclear power based power plants for electrical generation	kW
Wind Farm	Wind turbines based power plants for electrical generation	kW
Natural Gas Distribution	Steel pipes (10 inch diameter) used for natural gas distribution	miles
Water Distribution	Network of pipes used to distribute water for domestic and commercial use	miles
Water Purification	Water treatment plants to purify water	gal
Sewage Treatment	Wastewater treatment plants	gal
Warehouse	Warehouse to store goods, supplies and the likes.	sq. ft.
Wireless Towers	Cell towers in a cellular network	units
Wired Networks	Optical cable lines for fiber optic internet connection	miles
Communication Centers	Emergency response centers	sq. ft.
Hospital Facilities	Super specialty multi-bed healthcare facility	sq. ft.
Fire Stations	Facilities with fire engine, fire fighters, and fire retardant materials and equipment, and the likes.	sq. ft.
Police Stations	Facilities accommodating police personnel	sq. ft.
Railway Networks	Railway track lines to transport goods and ferry people	miles
Railway Bridges	Bridges used by railways to transport goods and passengers over roads, ravines, and the likes.	sq. ft.
Roadway Bridges	Bridges used by motor vehicles to transport goods and passengers over roads, rivers, and the likes.	sq. ft.
Elementary Schools	From kindergarten through grade 6	sq. ft.
Middle Schools	From grade 7 through grade 9	sq. ft.
High Schools	From grade 10 through grade 12	sq. ft.
Air Freight Facilities	Facilities to ship and receive air cargo	sq. ft.
Air Passenger Facilities	Domestic and International Airports	sq. ft.
Arterial Roads	Major and minor roads passing through a town/city	sq. ft.
Water Freight Facilities	Facilities to ship and receive cargo using riverboats and barges	sq. ft.
Interstates	Highways connecting two or more states	sq. ft.
Traffic Signals	Standard traffic signal poles	units
Street Lights	Standard street lighting poles	units
Rail Freight Facilities	Facilities to ship and receive cargo using railways	sq. ft.
Rail Passenger Facilities	Railway station to transport passengers	sq. ft.

Table 1: List of facilities included in the software. The table includes the description for each facility and the units that each facility is measured in.

FACTORS	DESCRIPTION	UNITS
Power (F_{i1})	Electric power needed for restoration tools and operations	kW per unit of the facility
Fuel (F_{i2})	Amount of gas needed to run power generator, tools, and construction equipment	gallon per unit of the facility
Potable Water (F_{i3})	Amount of clean drinking water needed by the restoration crew	gallon per unit of the facility
Storage Area (F_{i4})	Storage space used by restoration crew to store goods, tools, and the likes.	square foot per unit of the facility
Man-hours (F_{i5})	Labor hours spent by personnel working on restoration activities	hours per unit of the facility
Gray Water (F_{i6})	Water used for restoration and construction activities	gallon per unit of the facility
Black Water (F_{i7})	Wastewater containing fecal matter	gallon per unit of the facility
Solid Waste (F_{i8})	Garbage, construction waste and the likes.	pound per unit of the facility
Food (F_{i9})	Amount of food items needed by the restoration crew	pound per unit of the facility
Materials (F_{i10})	Construction material required to construct respective facilities	US Dollars per unit of the facility

Table 2: List of resources. The table includes a description for each resource and the units in which the resource is measured.

Mathematical Framework for the Application

The user specifies the amount of units of one or more infrastructure elements that need to be restored. If the user wanted to restore 'x' units of the element i, the resources are denoted by j, and the SCIRC tool would multiply the number of units, x, with each resource in the "Factors" tab for the element i. Equations (1) – (10) in table 3 give the formula for calculating the total amount of each resource required to restore an element i. Equation (11) in table 3 refers to the total cost of restoring x units of element i. C_j in equation 1 denotes the cost of one unit of resource j.

T_{i1} – Refers to the amount of power required to restore x units of facility i	$T_{i1} = x * F_{i1}$ eq. (1)
T_{i2} – Refers to the amount of fuel required to restore x units of facility i	$T_{i2} = x * F_{i2}$ eq. (2)
T_{i3} – Refers to the amount of potable water required to restore x units of facility i	$T_{i3} = x * F_{i3}$ eq. (3)
T_{i4} – Refers to the amount of storage area required to restore x units of facility i	$T_{i4} = x * F_{i4}$ eq. (4)
T_{i5} – Refers to the amount of man-hours required to restore x units of facility i	$T_{i5} = x * F_{i5}$ eq. (5)
T_{i6} -– Refers to the amount of gray water required to restore x units of facility i	$T_{i6} = x * F_{i6}$ eq. (6)
T_{i7} – Refers to the amount of black water generated while restoring x units of facility i	$T_{i7} = x * F_{i7}$ eq. (7)
T_{i8} – Refers to the amount of solid waste generated while restoring x units of facility i	$T_{i8} = x * F_{i8}$ eq. (8)
T_{i9} – Refers to the amount of food required to restore x units of facility i	$T_{i9} = x * F_{i9}$ eq. (9)
T_{i10} – Refers to the amount of materials required to restore x units of facility i	$T_{i10} = x * F_{i10}$ eq. (10)
T_{i11} – Refers to the total cost incurred to restore x units of facility i	$T_{i11} = \sum_{j=1}^{10}(T_{ij} * C_j)$ eq. (11)

Table 3: Mathematical equations for "Totals" tab.

Following the equations described above, “Totals” for multiple elements are calculated. Equation (12) calculates the overall resources, OR_{ij}. Here, i refers to the element and j refers to the resources included in the “Overall Resources” tab.

$$OR_{ij} = \sum_{i=1}^{30} T_{ij} \quad \forall\, j = 1,2,3, \ldots\ldots,11 \qquad \text{eq. (12)}$$

If there is only a single occurrence of an element to be restored, then the values in the “Totals” tab and “Overall resources” tab remain the same. If multiple occurrences or elements are to be restored, the “Overall Resources” tab shows the total amount of resources required to restore all occurrences for all elements.

Installation

The SCIRC tool is stored as a Python 2.7 executable file for the ease of the user. This application requires minimal effort for installation. The application is provided as an executable file format. The user can download the file from the link (http://web.mst.edu/~cornss/scirc/scirc.exe). Once downloaded, the user must double-click the saved file and select the 'Run' option in the dialog box. The user can now choose the location where they want to install this tool. After the software has been installed, the user can now double-click on the executable file to run the application. The user's computer must meet the minimum system requirements before installing and running the SCIRC application. The system requirements are shown in table 4.

CPU	1 gigahertz (GHz) or 32-bit(x86) or 64-bit (x64) processor
RAM	1 GB (32-bit) or 2 GB (64-bit)
Disk Space	60 MB
Operating System	Microsoft Windows version 7 or newer

Table 4: System requirements to run SCIRC.

Tutorial

Launching the application: To launch the application, double-click on the SCIRC executable file (SCIRC.bat).

User Interface: Once the application is launched, the user will see the main interface page of the software (fig. 2). The tabs Facilities Affected, Factors, Totals, and Costs are accessible as the top field of the table, while the Overall Resources tab is accessible in the horizontal bar positioned after the first bank of I/O boxes.

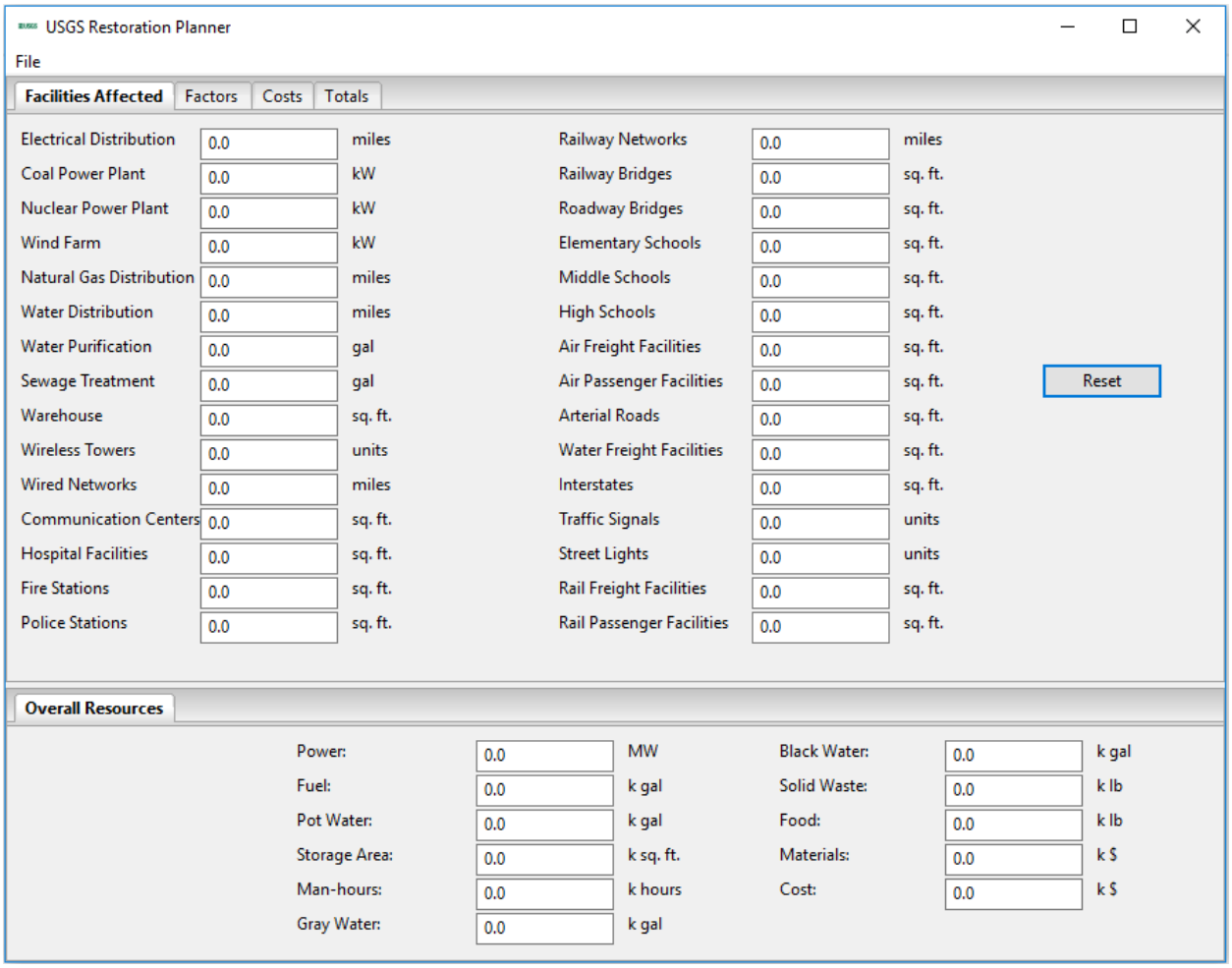

Figure 2: User Interface as seen when the application is launched.

Input: The user can input values for the desired infrastructure element in the box adjacent to that element (fig. 3). For example, to calculate the amount of resources required to restore 487,000 square feet of "High School" the user should:

1. Click on the box adjacent to "High School".
2. Input the value '487,000' in the box and press 'Enter' key on the keyboard.

The user can also input values for multiple facilities using the above steps. The user can click on the 'Reset' button at any time to make all the values in the Facilities Affected tab zero.

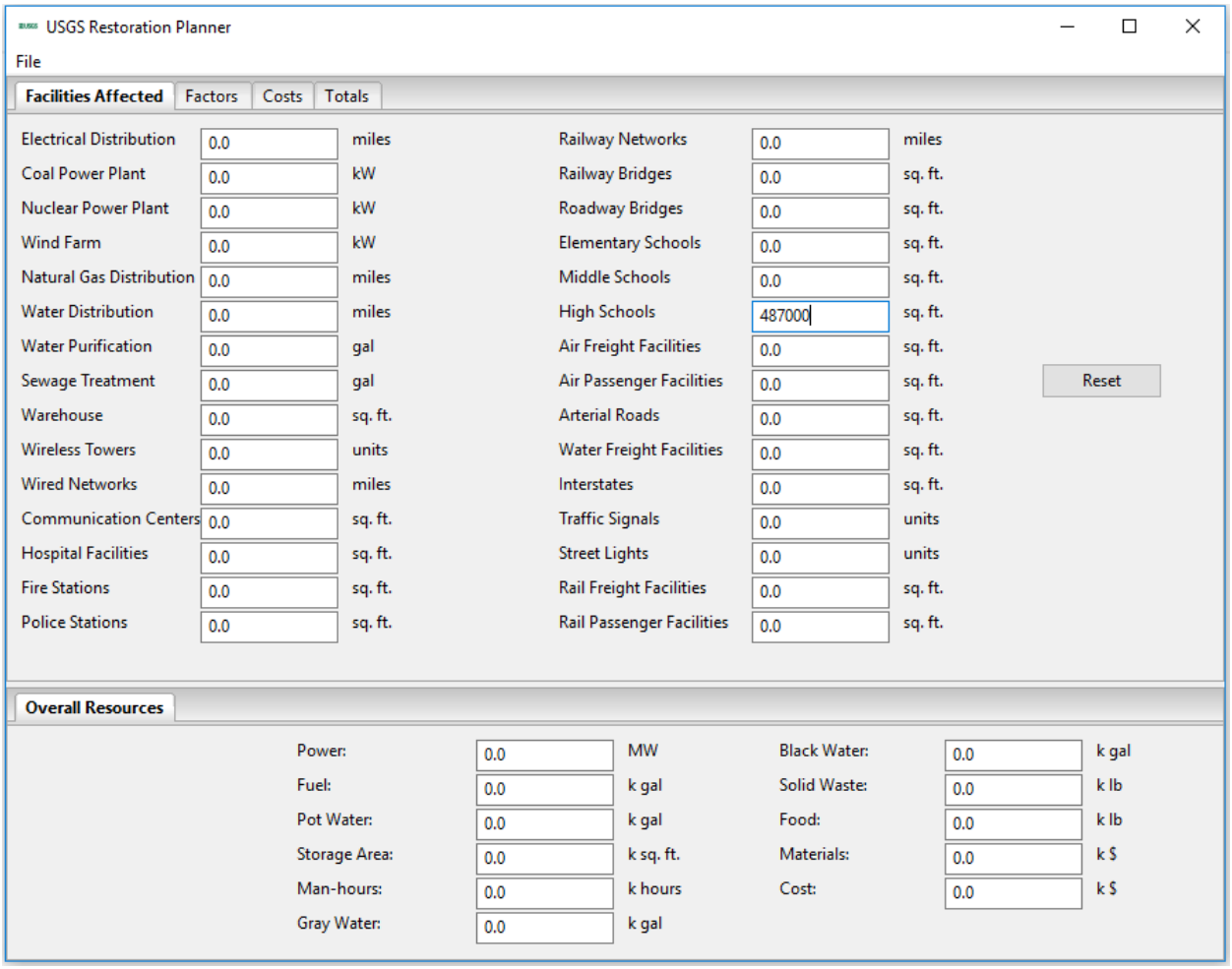

Figure 3: The user entering the value in the box adjacent to High Schools.

Output: Once the user has input the values in the Facilities Affected tab, the output can be seen in both Overall Resources and Totals Tab (fig. 4). The user accesses the amount of resources required to restore an individual element as follows:

1. Click on the Totals tab.
2. Click on the Select Facility drop-down menu.
3. Click on the element that the user wants to select from the drop-down menu. The amount of resources required to restore the user-specified units of the select facility can be viewed now (fig. 5).

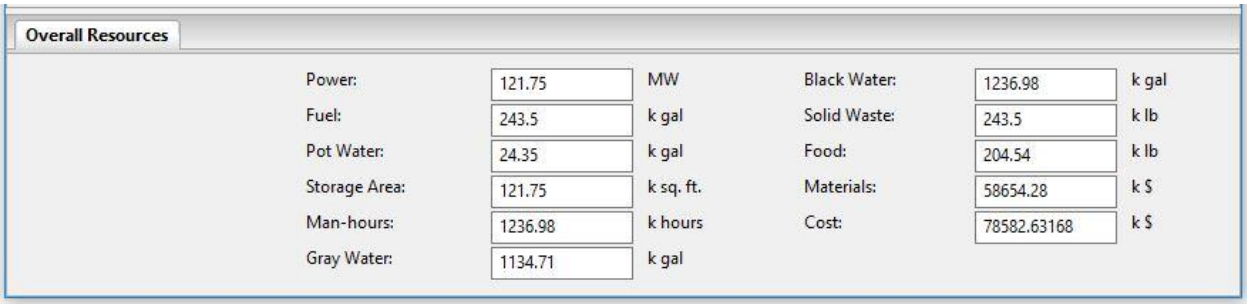

Figure 4: Overall Resources tab. The user can view the amount of resources required to restore one or more facilities here.

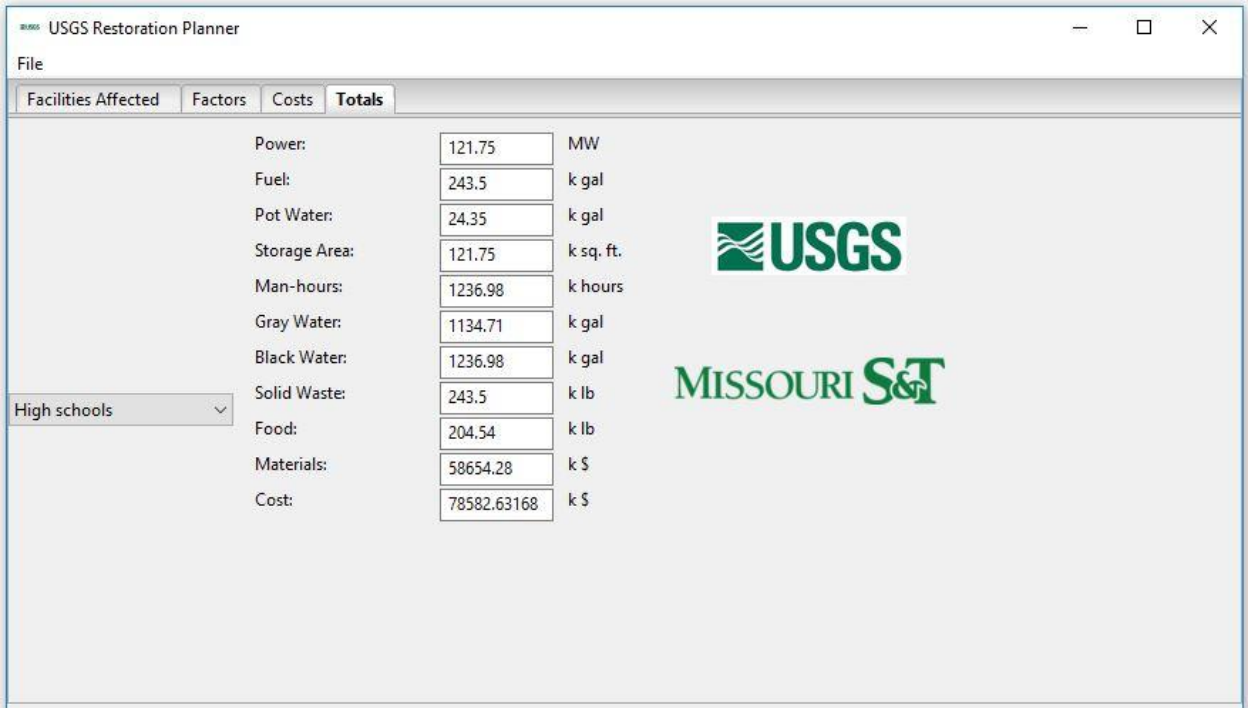

Figure 5: Totals tab. The user can select a facility from the drop-down menu and view the amount of resources required to restore an individual facility.

Flexibility of the application: Based on the need and/or expertise of the user, the user may want to change the values in the Factors and Costs tabs. The Factors tab gives the amount of resources required to restore one occurrence of an individual infrastructure element. The Costs tab provides the restoration cost of one occurrence of each necessary resource.

To modify the values in Factors tab, follow the steps below:

1. Click on the Factors tab and select an infrastructure element from the drop-down menu (fig. 6) for which the value should be modified (For example, High School).
2. Click on the box adjacent to the resource for which the value needs to be modified (For example, Man-hours).
3. Delete the value in the box by pressing the ‘Backspace’ or ‘Delete’ key on the keyboard.
4. Enter the value in the text box using the keyboard and press ‘Enter’.

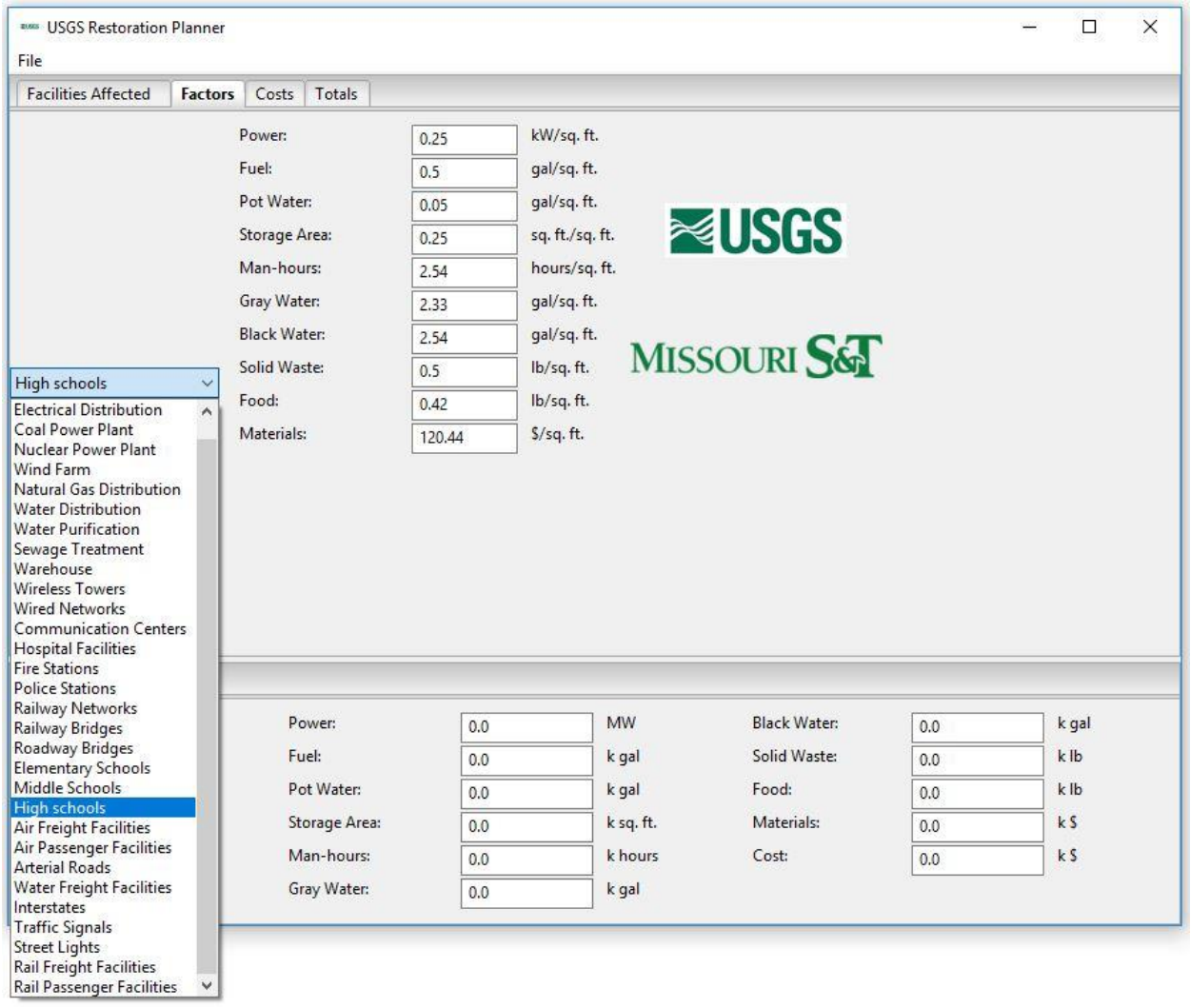

Figure 6: Factors tab. The user can select a infrastructure element from the drop-down menu and modify the value of one or more resources for that facility in this tab.

To modify the values in Costs tab, follow the steps below:

1. Click on the Costs tab.
2. Click on the box adjacent to the resource for which the cost needs to be modified (For example, Man-hours).
3. Delete the value in the box by pressing the ‘Backspace’ or ‘Delete’ key on the keyboard.
4. Enter the value in the box using the keyboard and press ‘Enter’.

Saving and opening a file: The user can save the results in an XML formatted file. The saved file can be opened in the application.

To save a file follow the steps listed below:

1. Click on the File menu.
2. Click on Save As and type the file name in the ‘Save file as’ dialog box. Note that the file must be saved in an XML format.
3. Click on Save to save the file.

To open a saved file, use the following steps:

1. Click on the File menu.
2. Click on Open to view the ‘Choose a file’ dialog box.
3. Select the file and click on Open. The selected file will be opened in the application.

Results

SCIRC calculates the resources required for restoring multiple facilities after catastrophic failure. Unlike traditional commercial software, this application also calculates the amount of resources required for the restoration crew while they perform the restoration operations. The total

cost provided by this software does not include overhead expenses such as accounting fees, advertising, legal fees, and profits. The cost and amount of supplies required by the restoration crew, however, are calculated. Table 5 provides a detailed comparison between the actual cost, (the actual cost of restoring elements using data from reconstruction after a tornadic event) and the cost of restoring a facility using the SCIRC tool along with the percentage difference between the actual and calculated cost for restoring a facility. A list of facilities that have been validated using these data is presented in table 5.

Facilities Affected	Unit of Facilities Affected	Actual Cost, $	SCIRC Cost, $	Percentage Cost Difference
Hospital	900,000 sq. ft.	168,000,000	168,531,674	-0.16%
High School	487,000 sq. ft.	89,740,786	97,137,331	8.24%
Elementary School	66,500 sq. ft.	10,800,000	11,251,868	4.18%
Middle School	125,800 sq. ft.	24,320,000	24,381,387	0.25%
Fire Station	7,500 sq. ft.	755,108	786,838	4.20%
Warehouse	10,000 sq. ft.	880,000	852,924	-3.08%
Police Station	5,000 sq. ft.	567,286	674,264	18.86%
Wired Networks	1 mile	16,632	16,695	0.38%
Railway Networks	1 mile	1,585,000	1,318,523	-16.81%
Traffic Signals	1 each	32,760	36,181	10.44%
Street Lights	1 each	5,200	5,342	2.73%

Table 5: Percentage cost difference between the actual and calculated costs for restoring a given facility.

Figure 7 compares the actual and SCIRC costs for fire stations, warehouses, police stations and railway networks. As the cost estimates from the SCIRC tool do not include contractor fee, architectural fee and profit, these costs are excluded from the actual costs of restoring different infrastructure elements for validation purposes.

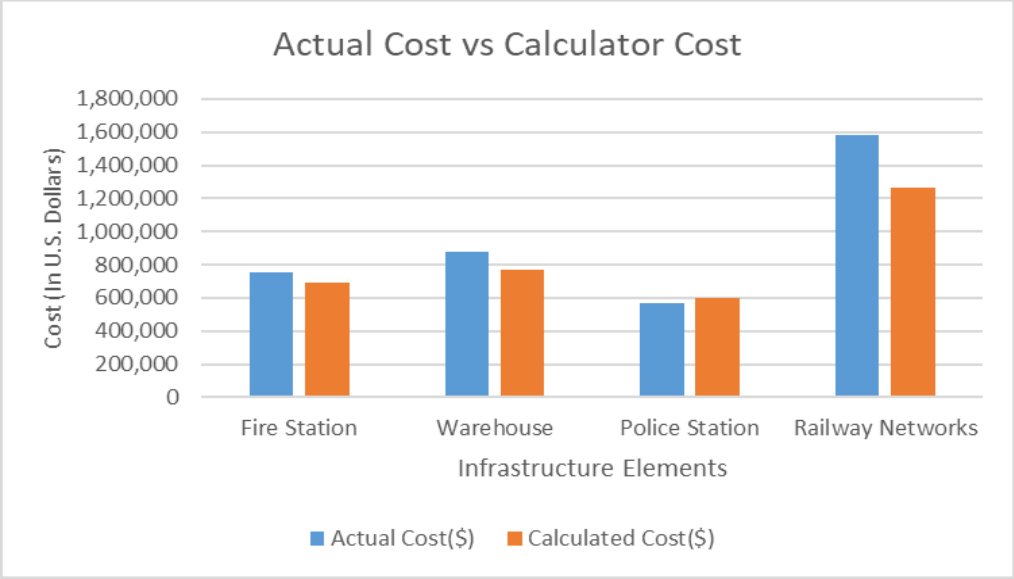

Figure 7: Actual Cost vs SCIRC Cost for Fire Station, Warehouse, Police Station and Railway Networks.

The actual and SCIRC costs for hospitals, high schools, elementary schools and middle schools are given in figure 8. Note that the cost used for validation does not include the cost of equipment used within these facilities. For instance, the cost of restoring a hospital does not include the cost of equipping it with X-Ray, CT scan, MRI and similar medical equipment. Also, the costs of furniture, computers, gym equipment and similar products required for day to day operation of the facility are not included in the total cost. Since hourly wage for a restoration crew member varies with the nature of work, an average hourly wage of $30 is assumed across all facilities for the restoration crew member.

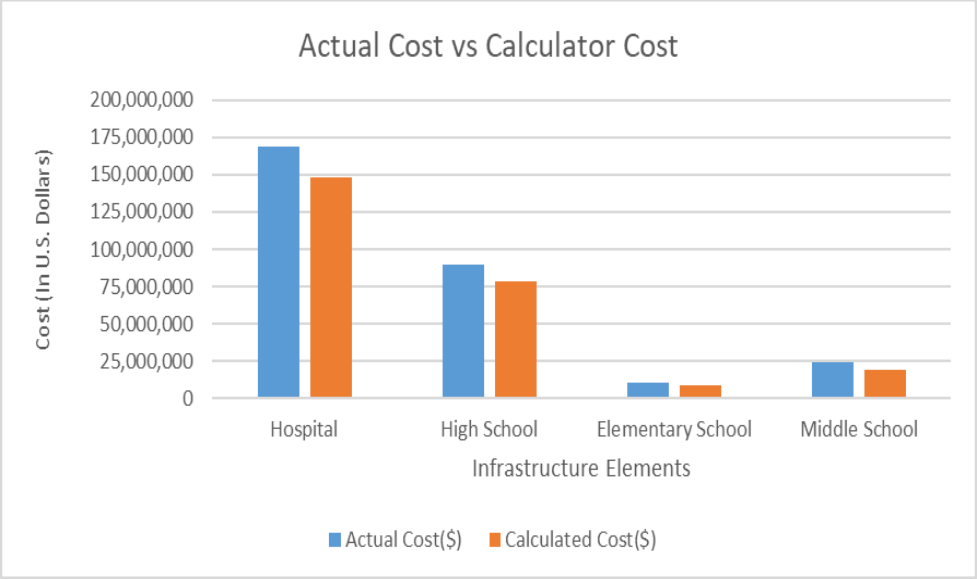

Figure 8: Actual Cost vs SCIRC Cost for Fire Hospital, High School, Elementary School and Middle School.

Actual and SCIRC cost values of wired networks, traffic signals and street lights are given in figure 9. For wired networks, the cost of optical fiber cable as well as the cost of installation of these optical fiber cables is included in the cost used for validating the results obtained from the SCIRC tool. The cost used to validate a traffic signal includes the cost of replacing one signalized post and mast arm, the cost of controller cabinet as well as the cost of installing the traffic signal. For street lights, the cost includes the cost of the light poles, bracket arms, controller, sensor, high pressure sodium lamp, and wiring and installation of the street light.

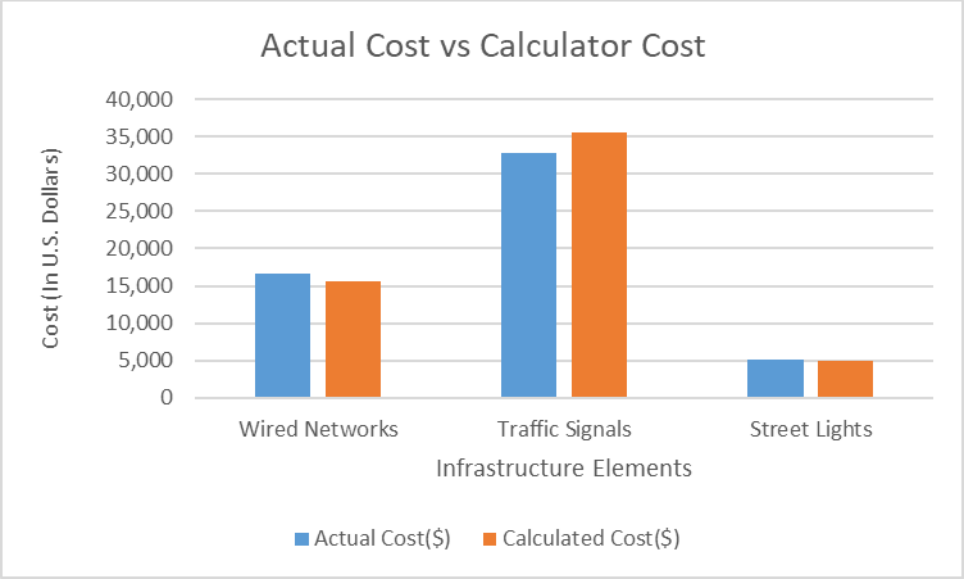

Figure 9: Actual Cost vs SCIRC Cost for Wired Networks, Traffic Signals and Street Lights.

Validation Parameters

The default values used by the SCIRC tool to calculate resource costs were gathered from government and industry sources indicative for the mid-western United States (EIA, 2018; EPA, 2018; MWEA, 2018; Boesler, 2013; Jiang, 2011). In some cases, default data (presented in Appendix I and II) were derived from a combination of cost estimates from other projected resource needs. In areas of the country where costs vary significantly from the mid-western values, the user can and should substitute local prices for the default values in the "Costs" tab.

Calculated results from the SCIRIC tool are validated against real-world data published in after-action reports following the F-5 tornado that devastated Joplin, Missouri on 22 May 2011. Facility costs were generally taken directly from published project reports, although some of the infrastructure elements available in the SCIRIC tool are distinct from cost categories in the published reports. In these cases, cost data are either derived or taken from state or federal reports for labor costs or from alternate published sources, such as construction bids and agency websites.

Table 6 lists the facilities along with the references from where the data has been extracted for validation. Standard construction bids include a 20% cost overrun in their cost markup. Because of this, a relative error range of ±20% is used as the acceptable error range. This goodness of fit incorporates industry practice and existing protocols for cost analysis (U.S. GAO, 2009).

Facilities Affected	References
Hospital Facilities	"Mercy Joplin Quick Facts." Mercy. Accessed July 22, 2018. https://www.mercy.net/newsroom/mercy-hospital-joplin-quick-facts/.
High Schools	"Filter Projects." DLR Group. Accessed July 22, 2018. http://www.dlrgroup.com/work/joplin-high-school/.
Elementary Schools	"Soaring Heights Elementary School." Hollis Miller. Accessed July 22, 2018. https://www.hollisandmiller.com/portfolio-posts/soaring-heights-elementary-school/.
Middle Schools	"East Middle School." Hollis Miller. Accessed July 22, 2018. https://www.hollisandmiller.com/portfolio-posts/east-middle-school/.
Fire Stations	"Commercial Cost Estimate." Commercial Construction Cost Calculator. Accessed July 22, 2018. http://www.buildingjournal.com/commercial-estimating.html.
Warehouse	"International Warehouse/Logistics Center Costs." Compass International. Accessed July 22, 2018. https://www.compassinternational.net/international-warehouse-logistics-center-costs/.
Police Stations	"Commercial Cost Estimate." Commercial Construction Cost Calculator. Accessed July 22, 2018. http://www.buildingjournal.com/commercial-estimating.html.
Wired Networks	"Knowledge Resources." RITA | ITS | Costs: Unit Cost Components for Fiber Optic Cable Installation. Accessed July 22, 2018. https://www.itscosts.its.dot.gov/its/benecost.nsf/DisplayRUCByUnitCostElementUnadjusted?ReadForm&UnitCostElement=Fiber Optic Cable Installation &Subsystem=Roadside Telecommunications.
Railway Networks	"2017 Railroad Engineering & Construction Costs." Compass International. Accessed July 22, 2018. https://www.compassinternational.net/railroad-engineering-construction-cost-benchmarks/.
Traffic Signals	Harper, Jennifer. "MoDOT Traffic Division." E-mail. July 18, 2018.
Street Lights	“Lindon City Street Lights Questions And Answers.” PDF file. Accessed July 22 2018. https://siterepository.s3.amazonaws.com/00442201006240906424493.pdf.

Table 6: A list of references used to validate different infrastructure elements.

Discussion

The SCIRC tool extends industry cost estimating tools in several ways. It is specifically designed to consider interdependencies and includes ratios that calculate how changes in one system or sub-system results in changes in other systems. It provides a holistic analytical capability to map the level of resources and manpower required to restore damaged systems. This integrated approach allows a unique mechanism for considering the cost-benefit of full restoration and can be used to determine whether rebuild or new construction options are the best choice.

SCIRC provides the user with the information about the amount of resources required to restore one or multiple facilities. The user can input the number occurrences of each infrastructure element that needs to be restored after an extreme event and the software calculates the amount of resources required for restoration. Quantifying the extent of damage caused by a disaster is crucial to restoration planning. This tool can be applied to a region affected by a disaster. Based on the severity of the disaster, the extent of damage to various infrastructure elements can be analyzed. If a hundred thousand square feet of a hospital, five miles of an interstate and hundred traffic signals are destroyed due to a tornado, the user can input the values for these destroyed infrastructures in the SCIRC tool and calculate the amount of resources that will be required to restore these infrastructures. The SCIRC provides a macro level view of the amount of resources required to restore an entire infrastructure network. The tool also provides information regarding the number of man-hours required to carry out restoration activities. This information can be used to calculate the number of personnel required for carrying out restoration operations and is useful in quantifying the amount of resources that would be required by the restoration crews while performing restoration operations. City planners and policy makers can use this tool for budgeting

and prioritizing post-disaster operations. Organizations overseeing restoration efforts and budget planning can use this tool to devise efficient disaster restoration strategies. Although the SCIRC tool can be used to calculate the direct costs associated with restoring different infrastructure elements, it is not very helpful for calculating the indirect costs accrued after one or multiple infrastructures are damaged due to an extreme event.

The software is flexible, it can be used to calculate the amount of resources required to restore multiple infrastructure elements and has the ability to be applied to different regions. Whereas most tools are specific to a single infrastructure, the SCIRC calculates the resources required for construction of multiple infrastructure elements of multiple types as required by a restoration scenario. A limitation of this software is that additional infrastructure elements cannot be added to the tool. Also, this tool lacks a feature to automatically update the value of costs based on different regions. However, the factors and costs can be manually updated by an individual based on their expertise and knowledge. The future work will allow the user to automatically update the value of costs by selecting the geographic region. Ultimately it would be possible to link the SCIRC tool with a GIS framework such as The National Map in order to calculate the amount of resources required to restore infrastructure elements by selecting a specific area on the map on a near-real time basis.

Summary

The SCIRC calculates the amount of resources required to restore one or more infrastructure elements after failure. The software calculates the total amount of resources required to restore one or more occurrences for each selected infrastructure element along with the cost of each resource.

The SCIRC can calculate results for thirty different infrastructure elements (table 1). The SCIRC calculates costs based upon a standardized average base for the country, but the user can tailor cost to a specific region by inputting the cost data manually. A unique contribution of the SCIRC is the ability to account for the resources required by restoration crews as well as the material resources necessary to restore the entire infrastructure network. The output from this software can be used by city planners and policy makers to devise efficient strategies for post-disaster restoration operations.

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Appendices

Appendix I: Default parameters for Facility factors (per unit of restoration metric)

Facility	Power KW/ unit	Fuel gal/ unit	Potable Water gal/ unit	Storage square feet/unit	Man Hours hours/ unit	Gray Water gal/ unit	Black Water gal/ unit	Solid Waste lb/ unit	Food lb/ unit	Materials $/unit
Electric Distribution	250	1500	72.92	15000	3500	3208.33	3500	700	583.33	145000
Coal Power Plant	5	2.25	0.0375	9.5	1.8	1.65	1.8	0.36	0.3	3200
Nuclear Power Plant	9	4.7	0.048	10	2.3	2.11	2.3	0.46	0.38	3800
Wind Farm	5	3.5	0.42	9	2	1.83	2	0.4	0.33	1500
Natural Gas Distribution	200	500	8.33	12500	400	366.67	400	80	66.67	70000
Water Distribution	100	200	8.33	5000	400	366.67	400	80	66.67	5000
Water Purification	0.2	0.2	0.002	1	0.1	0.092	0.1	0.02	0.017	2
Sewage Treatment	0.3	0.15	0.002	1.2	0.1	0.092	0.1	0.02	0.017	2
Warehouse	0.5	0.05	0.012	0.1	0.6	0.55	0.6	0.12	0.11	66.72
Wireless Towers	2300	600	1.67	500	80	73.33	80	16	13.33	184000
Wired Networks	2400	250	1.44	6000	68.92	63.18	68.92	13.78	11.49	10665.23
Communication Centers	0.25	0.5	0.019	0.5	0.9	0.825	0.9	0.18	0.15	92.97
Hospital Facilities	0.25	0.5	0.03	0.5	1.54	1.41	1.54	0.308	0.26	138.6
Fire Stations	0.25	0.5	0.02	0.5	0.86	0.79	0.86	0.17	0.14	77.02
Police Stations	0.25	0.5	0.02	0.5	0.98	0.9	0.98	0.19	0.16	103.3
Railway Networks	750	1500	80	15000	3500	3200	3500	715	580	1200000
Railway Bridges	0.104	0.34	0.009	1.319	0.469	0.429	0.469	0.094	0.078	972.22
Roadway Bridges	0.022	0.063	0.003	0.546	0.148	0.136	0.148	0.029	0.025	156.14
Elementary Schools	0.25	0.5	0.05	0.25	2.59	2.37	2.59	0.51	0.43	88.65
Middle Schools	0.25	0.5	0.05	0.25	2.55	2.33	2.55	0.51	0.42	114.49
High Schools	0.25	0.5	0.05	0.25	2.54	2.33	2.54	0.5	0.42	120.44
Air Transportation facility	2	7.5	0.042	1	2	1.83	2	0.4	0.33	75
Air Passenger Facilities	2.5	12.5	0.62	1.5	3	2.75	3	0.6	0.5	155
Arterial Roads	0.003	0.014	0.001	0.114	0.024	0.022	0.024	0.005	0.004	7.58
Water Freight Facilities	2	7	0.42	0.5	2	1.83	2	0.4	0.33	75
Interstates	0.003	0.012	0.001	0.094	0.02	0.018	0.02	0.004	0.003	14.04
Traffic Signals	25	50	0.94	75	45	41.25	45	9	7.5	34630
Street Lights	5	10	0.49	50	23.49	21.53	23.49	4.7	3.92	4572.3
Rail Freight Facilities	2	7	0.042	0.5	2	1.83	2	0.4	0.33	75
Rail Passenger Facilities	2.4	12	0.625	1	3	2.75	3	0.6	0.5	130

Appendix II: Default costs (Midwestern scale) for restoration activities.

Facility	Units	Costs
Power	$/Kw	0.097
Fuel	$/gal	2.781
Potable Water	$/gal	0.004
Storage Area	$/sq. ft.	0.5
Man-Hours	$/hr	30.0
Gray Water	$/gal	0.003
Black Water	$/gal	0.005
Solid Waste	$/lb	0.002
Food	$/lb	3.0